

## CHAPTER 12

### AGRICULTURE

#### 12.1 INTRODUCTION

This chapter presents methods for evaluating mitigation options for the agriculture sector.<sup>1</sup> The primary sources of GHG emissions in this sector include animal husbandry, rice cultivation, fertilizer application, and soil carbon in cultivated soils. The latter are also a potential carbon sink.

**Animal Husbandry.** Animal husbandry results in methane emissions from two main sources: enteric fermentation (the digestive processes of animals); and manure management system facilities. *Enteric fermentation* emissions are driven principally by the quality and quantity of feed consumed by ruminant animals (cattle, buffalo, sheep, goats, and camels). Non-ruminant livestock (swine, horses, and poultry) produce a relatively small amount of methane from enteric fermentation. Enteric fermentation by livestock has been estimated to account for about 65 to 100 Tg of methane emissions annually (IPCC, 1992); about 80 percent of these emissions are from the large ruminant animals: cattle and buffalo (USEPA, 1994).

Efforts to reduce methane emissions from enteric fermentation generally focus on options for improving *production efficiency*. Demand for animal products continues to increase globally, putting pressure on livestock production systems and competing land uses such as forestry. Improving production efficiency will not only help reduce these pressures and meet the growing demand, but also can reduce methane emissions per unit of product produced. To be considered viable, emissions reduction strategies must also provide an economic return for the producer and be ecologically sustainable.

**Manure** related emissions result from the anaerobic decay of organic material in livestock manure. Current estimates of methane emissions from livestock manure worldwide range from 10 to 18 Tg per year (approximately 2 to 5 percent of global annual anthropogenic methane emissions). Three animal groups account for more than 80 percent of total emissions: swine: 40 percent; non-dairy cattle: 20 percent; and dairy cattle: 20 percent (USEPA, 1994). Manure management systems that promote anaerobic conditions produce the most methane: liquid/slurry storage facilities (tanks and pits) and anaerobic lagoons. While a relatively small percentage of livestock manure worldwide is managed in this manner, these systems are responsible for about 60 percent of global livestock manure methane emissions (USEPA, 1994). In contrast, management techniques which involve contact of the manure with air (e.g., uncollected on the range or spread directly on crops or pasture land) have limited methane production potential.

Efforts to reduce methane emissions from manure management facilities focus on options for recovering and using the methane produced. Techniques for reducing emissions should also maintain the fertilizer value of the material, as well as provide a cost effective means of handling the manure.

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<sup>1</sup>Options for mitigating emissions from energy use in agriculture are discussed in Chapter 7.

Rice Cultivation. Methane is emitted from flooded rice fields (both rain-fed and irrigated) due to the anaerobic decomposition of organic matter in the paddy soil. Current estimates of methane emissions from flooded rice fields worldwide range from 20 to 150 Tg per year (IPCC, 1992), making it one of the largest anthropogenic sources of methane emissions globally.<sup>2</sup>

The principal approach for reducing methane emissions from flooded rice cultivation is to modify growing practices. Research is ongoing to identify and evaluate options for reducing methane emissions by managing the input of organic material to the cropping system and/or modifying the flooding regimes to alter the anaerobic conditions that lead to methane formation.

While research on alternative growing practices appears promising, significant investigation remains to assess the complex set of factors that affect the methane emission process from flooded rice fields.<sup>3</sup> In particular, the impacts of alternative growing practices on production as well as methane emissions over extended periods of time remain to be quantified. Because rice plays a critical role in the culture and diets of over one billion people globally, options for mitigating emissions must therefore satisfy the following criteria:

- improve rice productivity;
- provide a positive economic return to the producer;
- not require significant amounts of hard currency; and
- be ecologically sustainable.

Fertilizer Application. It is well documented that nitrous oxide ( $N_2O$ ) is accumulating in the atmosphere, but the activities that are leading to this accumulation have yet to be well quantified. It has been suggested, however, that about 70 percent of  $N_2O$  emissions originate from soils (Bouwman, 1990 and IPCC, 1992). Consequently, perturbations to the soil nitrogen (N) cycle are believed to be contributing to the increase in atmospheric  $N_2O$  concentrations. While a variety of factors influence the nitrogen (N) cycle in soils, the increase in N input to soil systems is one factor that has been quantified (Mosier, 1993).

Nitrogen can be added to soils for crop production through the application of N fertilizers and organic materials (animal manure, crop residues, sludge from municipal or individual treatment/storage facilities), by the cultivation of nitrogen fixing plants, through the application of irrigation water containing dissolved N, and from precipitation. Experimental and monitoring data show that the application of nitrogen to cultivated soils increases N emissions from the soil to the atmosphere. However, the transport and fate of N depends on numerous soil characteristics, the

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<sup>2</sup>Most of the methane associated with rice cultivation is produced in irrigated and rain-fed wetland rice fields, which comprise over 75 percent of the area of global cultivated rice fields. Neither dry upland rice fields nor deepwater rice are believed to produce significant amounts of methane. Because 90 percent of worldwide rice production occurs in Asia (Braatz and Hogan, 1991), this region accounts for the majority of methane emissions from rice cultivation.

<sup>3</sup>The methane which is not oxidized (in the upper layers of soil or inside the plant itself) is released into the atmosphere by plant-mediated transport and by diffusion and ebullition through the floodwater. The amount of methane released is affected by the following factors: soil factors (temperature, pH, redox potential); nutrient management; water regimes; cultivar; and cultivation practices.

fertilizer formulation, fertility profile of the soil, moisture regime, and management. When applied to a crop, 100 kg of fertilizer N could result in 50 of the 100 kg of N harvested in the crop, and 50 lost by the combination of leaching (25 kg), surface runoff (5 kg), and gaseous losses (20 kg). A combination of conventional wisdom and limited research data indicates that 5% to 10% (1 to 2 kg) of the gaseous emissions will be  $N_2O$ . The remaining makeup of the gaseous emissions will include ammonia ( $NH_3$ ), elemental nitrogen ( $N_2$ ), and various oxides of N ( $NO_x$ ).

Use of fertilizer N is essential for obtaining desired crop yields. Appropriate N management practices have the benefit of improving fertilizer N use efficiency, enhancing crop growth and quality, protecting surface water and groundwater quality, and reducing emissions of  $N_2O$  to the atmosphere. Some of the practices that should be included in a nitrogen management program are: 1) soil testing; 2) timing of N application to when it is needed by the crop; 3) accounting for the residual N in the soil and the N nitrification potential of the soil; 4) establishing a reasonable yield goal based on the soil/crop; 5) accounting for N mineralization and N from legumes, animal manure and other organic waste, and irrigation water (CAST, 1992).

Although ongoing research clearly indicates that N-gas emissions can be reduced by implementing fertilizer management techniques, more information is needed to define and improve N fertilizer management practices to minimize losses of  $N_2O$  to the atmosphere. However, understanding of the processes involved is evolved well enough to permit the formulation of defensible mitigation strategies. Through the use of the analytical technique formulated in the computer model NLEAP ("Nitrate Leaching and Economic Analysis Package"), the gross emission of N gasses to the atmosphere can be determined (Schaffer et al., 1991). NLEAP accounts for movement of N throughout the primary flow circuit of the nitrogen cycle including the amount of N-gas emitted to the atmosphere. The specific amount of  $N_2O$  in the emitted gas, under a range of conditions, is not known with certainty, and is the subject of further research. However, the total amount of gas emitted can be calculated through use of NLEAP. With additional development of NLEAP along with collection of experimental and field data, the amount of  $N_2O$  in the total amount of gas emitted can be estimated based on the site variables.

Soil Carbon in Cultivated Soils. Cultivated soils are believed to be a source of carbon emissions because cultivation of soils has been shown to lower their organic carbon content (Cole et al., 1993; Duxbury and Mosier, 1993; Lee, Phillips, and Liu, 1993). The soil carbon loss occurs within about 25 years following the initial conversion of the native land cover to cultivated conditions. Following this initial loss, the amount of soil carbon will generally stabilize at a level consistent with the cultivation practice used.

Loss of soil organic carbon (SOC) occurs due to both enhanced mineralization of organic matter and erosion. The extent to which the loss of SOC contributes to increases in the atmospheric concentration of carbon dioxide ( $CO_2$ ) is not known, however (Duxbury and Mosier, 1993). Much (if not most) of the SOC is likely lost through erosion, by wind or water. For example, Lee et al. (1993) estimated that 35% of current SOC loss from soils in the U.S. cornbelt is by water erosion. Much of the eroded soil is deposited near the site of erosion, while some is transported to more distant locations with considerably different environmental conditions. Often, but not always, oxidation of SOC under these conditions is slower than at the original site. The uncertainty in the fate of SOC

transported through erosion translates into an uncertainty in the estimate of the amount of CO<sub>2</sub> released from or sequestered by agricultural soils.

The use of alternative tilling practices can not only reduce the rate of SOC loss, it can also lead to a net accumulation of carbon in the soil. As such, changing tilling practices to accumulate SOC can help mitigate CO<sub>2</sub> emissions from other sources. The most promising opportunities for accumulating SOC are in areas where conventional tillage practices can be replaced with conservation tillage practices.

## **12.2 POTENTIAL MITIGATION OPTIONS**

### **12.2.1 Animal Husbandry**

#### ***Enteric Fermentation***

The conditions under which livestock are managed vary greatly. Options for reducing emissions must be selected to be consistent with country-specific circumstances, including: animal management practices (including cultural traditions); feed resources; market conditions; and economic development priorities. Although there are differences among various countries, one common strategy for reducing methane emissions is to increase animal production efficiency (e.g., milk production in cows, reproductive efficiency of cows maintained to produce calves, and the stamina and strength of draft animals). Virtually all efforts that improve animal productivity will reduce methane emissions per unit of product produced.<sup>4</sup>

The ability to reduce methane emissions per unit of product produced has been demonstrated in various countries with intensive animal production systems. Experience has shown that proper veterinary care, sanitation, ventilation (for enclosed animals), nutrition, and animal comfort provide the foundation for improving production efficiency and reducing methane emissions. In many cases, focusing on these basics provides the best opportunity for improving production efficiency. Within this context, a variety of techniques can help improve animal productivity and reduce methane emissions per unit of product.

The following are the main strategies identified to date for reducing methane emissions from ruminant livestock. Specific approaches for each of these strategies are summarized in Appendix 12-1 and described in more detail in USEPA (1993b).

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<sup>4</sup>The methane emissions per unit of product produced vary substantially among regions and livestock production systems. For example, while a highly productive cow may emit 120 kg of methane per year, she may also produce 7,000 kg of milk, resulting in a release of 17 grams of methane per kilogram of milk produced. In comparison, a smaller cow on a straw based diet may emit 50 to 60 grams of methane per kilogram of milk produced (Leng, 1991).

- Improved Nutrition Through Mechanical and Chemical Feed Processing: Improved nutrition reduces methane emissions per amount of product produced by enhancing animal performance, including weight gain, milk production, work production, and reproductive performance. Methane emissions per amount of digestible energy consumed by the animal may also be reduced. This option is applicable to accessible ruminant animals with limited feed resources. Assuming that feed digestibility is increased by 5 percent, methane emissions per unit product produced may decrease on the order of 10 to 25 percent, depending on animal management practices.
- Improved Nutrition Through Strategic Supplementation and Other Methods: Improved rumen function will reduce methane emissions per amount of feed consumed. Also, by providing additional microbial and/or by-pass protein to the animal, emissions per amount of product produced will be reduced by enhancing animal performance, including weight gain, milk production, work production, and reproductive performance. Improved rumen function may reduce methane emissions by about 5 to 10 percent. In addition, emissions per unit product may be reduced by 25 to 75 percent due to substantial increases in animal productivity that are anticipated under specific conditions (Leng, 1991).
- Production Enhancing Agents: Certain agents can act directly to improve productivity and reduce methane emissions per unit product. While various agents are under development, two agents that are currently available commercially are bST and anabolic steroid implants.
- Improved Production Through Improved Genetic Characteristics: Genetic characteristics are limiting factors mainly in intensive production systems. Continued improvements in genetic potential will increase productivity, and thereby reduce methane emissions per unit product.
- Improved Production Efficiency Through Improved Reproduction: Large numbers of ruminant animals are maintained for the purpose of producing offspring. Methane emissions per unit product can be significantly reduced if reproductive efficiency is increased. Improved nutrition described above can improve reproduction. Additionally, there are options for addressing reproduction directly.

The technical applicability of these approaches to the main livestock management systems is summarized in Table 12-1. For example, for small scale dairy and draft animal production systems and subsistence mixed farming production systems (generally found in developing countries), a range of options is applicable, including: improved feed processing; improved nutrition through the use of supplements; and genetic improvements through breeding programs.



In addition to the technical applicability defined in Table 12-1, additional criteria for assessing whether reducing emissions from ruminant livestock is a promising avenue for reducing GHG emissions include the following.

- Population of Large Ruminant Livestock. The emissions reductions that can be achieved are a function of the size of the population of large ruminant animals, cattle and buffalo. These options for reducing emissions should be considered if methane emissions from cattle and buffalo are a significant component of the total GHG emissions for the country.
- Conditions Must Support Efforts to Improve Production Efficiency. These emissions reduction options will be most effective when conditions in the country support efforts to improve production efficiency in the livestock sector. Examples include the following:
  - *Economic Development.* Economic development priorities that include the livestock sector are a useful complement to emission reduction efforts. Improved production and resulting incomes, for example among small scale dairy producers, can both reduce methane emissions per unit of product and improve rural economic conditions.
  - *Marketing Infrastructure.* When production efficiency is increased in areas of low productivity (as may be the case in developing countries), the product marketing infrastructure can become stretched. Efforts to improve marketing arrangements and infrastructure are a necessary complement to initiatives to reduce emissions.
  - *Education.* Educational opportunities for livestock producers, e.g., on-farm from agriculture extension services, may be one component of efforts to promote the use of emissions-reducing practices. Such programs could be one avenue for implementing the emissions reduction initiative.

In some countries, producer cooperatives have successfully created a climate that supports improvements in production efficiency. For example, cooperatives can provide training, assist in product marketing, and improve cash flow for producers, enabling them to invest in productivity enhancing practices. Working with producer cooperatives to improve production in a manner that also reduces methane emissions may be an attractive approach for some countries.

#### *Manure Management System Facilities*

Manure management system facilities that promote anaerobic conditions produce the most methane, including liquid/slurry storage facilities (pits and tanks) and anaerobic lagoons. The preferred approach for reducing methane emissions from manure management facilities is to recover the methane produced and combust it; in the process the methane can be used as an energy source. Methane recovery technologies have been successfully used and demonstrated under a variety of conditions, and have been shown to reduce emissions by up to 70 or 80 percent (USEPA, 1993b). Three main approaches have been identified (Table 12-2 summarizes the characteristics of these techniques).

**Table 12-2**  
**Summary of Methane Recovery Techniques for Livestock Manure**

Considerations	Covered Lagoons	Large Scale Digesters	Small Scale Digesters
Technique	<ul style="list-style-type: none"> <li>Impermeable Lagoon Covers</li> </ul>	<ul style="list-style-type: none"> <li>Complete Mix</li> <li>Plug Flow</li> </ul>	<ul style="list-style-type: none"> <li>Fixed Dome</li> <li>Floating Holder</li> <li>Flexible Bag</li> </ul>
Gas Quality	<ul style="list-style-type: none"> <li>Medium Quality (600-800 Btu/cf) (22-29 MJ/m<sup>3</sup>)</li> </ul>	<ul style="list-style-type: none"> <li>Medium Quality (600-800 Btu/cf) (22-29 MJ/m<sup>3</sup>)</li> </ul>	<ul style="list-style-type: none"> <li>Medium Quality (600-800 Btu/cf) (22-29 MJ/m<sup>3</sup>)</li> </ul>
Use Options	<ul style="list-style-type: none"> <li>Electricity Generation</li> <li>Boilers, Refrigeration, Other</li> <li>Fertilizer, Feed Supplement, Other</li> </ul>	<ul style="list-style-type: none"> <li>Electricity Generation</li> <li>Boilers, Refrigeration, Other</li> <li>Fertilizer, Feed Supplement, Other</li> </ul>	<ul style="list-style-type: none"> <li>Electricity Generation</li> <li>Domestic Gas Use</li> <li>Fertilizer, Feed Supplement, Other</li> </ul>
Availability	<ul style="list-style-type: none"> <li>Currently Available</li> </ul>	<ul style="list-style-type: none"> <li>Currently Available</li> </ul>	<ul style="list-style-type: none"> <li>Currently Available</li> </ul>
Capital Requirements	<ul style="list-style-type: none"> <li>Low/Moderate</li> </ul>	<ul style="list-style-type: none"> <li>Moderate</li> </ul>	<ul style="list-style-type: none"> <li>Low</li> </ul>
Technical Complexity	<ul style="list-style-type: none"> <li>Low Technology</li> </ul>	<ul style="list-style-type: none"> <li>Moderate Technology</li> </ul>	<ul style="list-style-type: none"> <li>Low Technology</li> </ul>
Applicability	<ul style="list-style-type: none"> <li>Temperate, Tropical</li> <li>Flush Systems; Low %TS<sup>2</sup></li> </ul>	<ul style="list-style-type: none"> <li>Temperate, Tropical</li> <li>2-15 %TS<sup>2</sup></li> </ul>	<ul style="list-style-type: none"> <li>Temperate, Tropical</li> <li>7-15 %TS<sup>2</sup></li> </ul>
Methane Reductions <sup>1</sup>	<ul style="list-style-type: none"> <li>Up to 80%</li> </ul>	<ul style="list-style-type: none"> <li>Up to 70% or more</li> </ul>	<ul style="list-style-type: none"> <li>Up to 70%</li> </ul>

<sup>1</sup> These are reductions which may be achieved at an appropriate individual site.

<sup>2</sup> Percent Total Solids (%TS) is a measure of the concentration of the manure in water.

Source: USEPA (1993c).



Covered Lagoons: Covered lagoons treat and store manure along with the large quantities of water used to wash the manure solids out of livestock housing facilities. The manure is treated under anaerobic conditions, resulting in the production of significant amounts of methane, which is recovered using an impermeable floating lagoon cover. The methane generated from these systems is often sufficient for the energy needs of large scale, intensive farm operations. Because their technology and capital needs are relatively low, covered lagoons may be appropriate for large farm operations in developing countries, especially those which need the high quality liquid fertilizer that lagoons produce. The use of lagoons in arid regions, however, may be constrained by their high water requirements.

Small Scale Digesters: Digesters are designed to enhance the anaerobic decomposition of organic material and to optimize methane production and recovery. Small scale digesters typically require a small amount of manure and are relatively simple to build and operate. As such, they are an appropriate strategy for small to medium confined or semi-confined farm operations. These digesters are also well-suited for regions with technical, capital, and material resource constraints, and have already been implemented successfully in countries such as China and India (United Nations, 1984). The digesters offer additional benefits in agricultural regions where manure is currently burned for fuel, as the generated methane is a cleaner and more efficient fuel. In addition, digested manure retains most of its fertilizer value. Small scale digesters generally operate best in temperate and tropical areas. Three common types of these digesters include the fixed dome, floating gas holder, and flexible bag.

Larger Scale Digesters: These digesters are also designed to enhance anaerobic decomposition and optimize methane recovery, but have larger capacities and are often more technologically advanced. They are generally heated, and can operate in relatively cold regions. Because larger scale digesters require greater capital investment, are more complex to build and operate, and require large concentrations of manure, they are best suited for large livestock operations. These technologies are especially suitable at operations which handle manure as liquids (less than 10 percent solids) or slurry (10 to 20 percent solids).

The criteria for considering the implementation of these emissions reduction techniques include the following:

- Emissions. The emissions reductions that can be achieved are a function of the amount of manure currently handled in a manner that produces methane emissions. These options for reducing emissions should be considered if methane emissions from liquid-based manure management facilities are a significant component of the total GHG emissions for the country.
- Conditions Must Support the Recovery and use of the Methane. These emissions reduction options will be most effective when conditions in the country support efforts to recover the methane and use it as an energy source. The most promising opportunity for implementing methane recovery is a large confined animal production facility using a liquid manure handling system. High local energy prices (which would increase the value of the methane recovered) make these options attractive. Small scale

implementation can also be attractive, particularly if an alternative energy source is desired (e.g., due to depletion of forest resources).

In addition to recovering methane from manure facilities, methane emissions can be reduced by keeping the manure under aerobic conditions. Manure spreading on soils and composting are the primary approaches for maintaining aerobic conditions. When undertaking spreading, care must be exercised in the rate of application on land to protect groundwater quality and to prevent unwanted runoff. Also, spreading must generally be restricted during periods when the ground is frozen, making it unfeasible in some areas.

Composting is a good alternative for managing manure because the compost it produces is a valuable fertilizer. Care must be taken to prevent unwanted runoff from the compost facility. Additionally, the potential for methane to be emitted from unwanted anaerobic conditions that may develop within the compost remains to be assessed.

### **12.2.2 Rice Cultivation**

Efforts to date have identified a number of approaches which could reduce methane emissions from rice cultivation while maintaining the productivity of the rice fields (IPCC, 1990; Braatz and Hogan, 1991). Two of the most promising approaches under investigation are changes in nutrient management and water management practices (USEPA, 1993c):

- **Nutrient Management.** Research indicates that using nitrogen (N) fertilizers and reducing the use of raw organic materials as fertilizer can reduce methane emissions from rice fields. Additionally, the form of the N fertilizer and the method of application may be important. This option may be promising because N fertilizers are already a major nutrient source for flooded rice fields in Asia. The major constraints to this option are the cost of N fertilizers, which may be prohibitive in some regions, and the existence of traditional fertilization techniques, which may be difficult to change. Additionally, care should be taken to apply N fertilizers in a way that N<sub>2</sub>O emissions (see below).
- **Water Management.** Intermittent draining of rice fields during the growing season or between croppings appears to decrease methane production, as does increasing the water percolation rate in the fields. These methods may be technically feasible in lowland regions and flatland irrigated areas, which have secure and controllable water supplies. Proposed changes in water management practices must be researched carefully in order to avoid decreasing productivity.

The impacts of these approaches on methane emissions and rice production remain to be quantified fully. Research indicates, for example, that there are interactions among fertilizer type, application method, and soil type that may affect methane emissions. Additionally, the impacts of intermittent field drainage on weed growth and rice production are still being researched. Examples of recent and ongoing research and assessments include the following: Kern *et al.* (in press), Olszyk *et al.* (1993); Masscheleyn *et al.* (1993); and Wang *et al.* (1993a and 1993b).

Efforts are also ongoing to examine other avenues for reducing emissions, including the following (Braatz and Hogan, 1991):

- Cultivar Selection. Developing rice cultivars which result in lower methane emissions may be a feasible option, and can be practical as long as rice productivity and other desirable characteristics are not compromised.
- Cultivation Practices. Opportunities may also exist for mitigating methane emissions by altering existing rice cultivation practices, such as tillage and seeding techniques. While certain changes in practices have been shown to reduce emissions, however, this strategy may be impractical. Existing cultivation practices have often been developed to suit physical, biological and socioeconomic conditions, and may be the most appropriate methods for each region.

Research in this area is continuing at the International Rice Research Institute and among key rice-growing nations, including India and China. Countries are encouraged to evaluate options they believe promising as part of their mitigation analyses.

### 12.2.3 Fertilizer Application

Although the factors that affect  $\text{N}_2\text{O}$  emissions from nitrogen application are not completely understood, there are several nitrogen management techniques known to be effective in reducing overall N-based emissions. Control of the nitrate form of nitrogen,  $\text{NO}_3$ , is the critical aspect of managing  $\text{N}_2\text{O}$  emissions, and is the central focus of the management techniques listed below:

- Test soils to determine fertilizer N needs.
- Establish yield goals based on site and crop characteristics.
- Establish yield goals based on site and crop characteristics. Set fertilizer rate and timing of application.
- Select N fertilizer formulation related to yield, leaching and runoff potential, and emissions.
- Account for animal manure and other organic waste where used in the fertility program.
- Use of winter cover crops for removal of residual N.
- Place N deeper in the soil.
- Implement irrigation water management techniques.
- Use nitrifying and denitrifying inhibitors.

### 12.2.4 Soil Carbon in Cultivated Soils

While there are uncertainties in the estimates of carbon dioxide emissions from cultivated soils, the use of conservation tillage techniques have shown to be effective in reducing SOC loss and, in some cases, can lead to SOC accumulation (Kern and Johnson, 1993). As alternatives to conventional tillage practices, conservation tillage techniques were developed to reduce water and

wind erosion, conserve soil moisture, and reduce fuel requirements. While they have the potential to reduce production costs, conservation tillage techniques require a higher level of farming skill.

Conservation tillage systems manage crop residues with a reduced amount of tillage, and in some cases no tillage. In a mulch till approach, a mulch of crop residues is maintained to protect the soil against raindrop impact and wind, slow evaporation, increase water storage, and slow organic matter decomposition. No-till approaches consist of no tilling after harvest to planting time. No-till can be combined with the addition of a cover crop to further protect the soil. Table 12-3 summarizes the practices for conventional tillage and three examples of conservation tillage systems for continuous corn production. Although the examples were developed for U.S. conditions, the concepts are applicable for all cultivation practices.

The costs and benefits of these mitigation approaches remain to be assessed, however. Research in this area is continuing, and countries are encouraged to evaluate options they believe promising as part of their mitigation analyses.

## **12.3 OVERVIEW OF THE MITIGATION ASSESSMENT PROCESS**

The following four steps are recommended for performing a mitigation option analysis.

Step 1: Develop Scenario Inputs Scenario inputs, such as area under rice cultivation, number of days under cultivation, the number of animals by type, etc. are decided in this step.

Step 2: Identify Target Sub-groups to be the Focus of the Emissions Reduction Effort and Refine the Emissions Estimates for the Sub-group The purpose of this step is to focus the analysis on those portions of the GHG source that are amenable to control. The target sub-groups are selected based on the applicability of the mitigation options for the source. A more detailed baseline emissions estimate is then developed for the target sub-groups.

Step 3: Evaluate the Mitigation Options for the Sub-group The purpose of this step is to evaluate the impacts that the mitigation options have on the emissions and other characteristics of the target sub-group.

Step 4: Develop Baseline and Mitigation Emissions Scenarios The purpose of this step is to integrate the information developed in Steps 1, 2 and 3 in order to develop both baseline and mitigation emissions scenarios.

Section 12.4 summarizes the inputs needed for baseline and mitigation scenarios. Section 12.5 summarizes Steps 2 and 3, identifying the target sub-groups and evaluating the mitigation options. Section 12.6 summarizes development of the baseline and mitigation scenarios.

<b>Table 12-3</b> <b>Operations for Conventional and Conservation Tillage:</b> <b>U.S. Continuous Corn Production</b>				
Operation	Conventional Tillage	Conservation Tillage		
		Mulch Till	No-till	No-till & Cover
Tandem Disk	Y			
N Fertilizer	Y	Y	Y	Y
Tandem Disk	Y	Y		
Field Cultivator	Y	Y		
Row Planter	Y	Y	Y	Y
Rotary Hoe	Y			
Row Cultivator	Y	Y		
Row Cultivator	Y			
Harvest	Y	Y	Y	Y
Tandem Disk	Y			
P Fertilizer	Y	Y	Y	Y
Twisted Point Chisel	Y	Y		
Plant Winter Wheat				Y
Shred, Kill Wheat				Y
Source: Lee, Phillips, and Liu (1993).				

## 12.4 SCENARIO INPUTS

The IPCC/OECD emissions inventory methodologies identify the inputs needed to estimate GHG emissions for 1990 or an alternative base year (IPCC/OECD, 1994). Scenarios of future emissions, with and without the implementation of mitigation options, may be developed by forecasting the key variables that drive the emissions.

### 12.4.1 Animal Husbandry

The IPCC/OECD emissions inventory method has the following steps:

- collect information on the animal populations;<sup>5</sup>
- estimate emissions factors per animal from the IPCC/OECD recommended values (or based on more detailed calculations presented in the method); and
- multiply the emissions factors by the relevant livestock populations.

If national data are lacking, the FAO Production Yearbook presents data on animal populations. The IPCC/OECD guidelines presents emissions factors that can be used for the baseline emissions estimates. Information on the portion of manure that is managed in each of the main types of facilities should be obtained from national livestock experts.

The baseline scenario of future emissions can be developed using a simple method or a complex method. The simple method is driven by scenarios of the future production of animal products, such as milk, meat, and draft power. For each animal type, an average emissions factor per unit of production is estimated for 1990 based on the 1990 inventory. The emissions factors are then multiplied by estimated future production to estimate future emissions, as follows:

$$\text{Emissions}_{i,t} = \text{Production}_{i,t} \times \text{Emissions Factor}_{i,1990}$$

where:

Emissions<sub>*i,t*</sub> is the estimate of emissions for animal type *i* in year *t*,  
Production<sub>*i,t*</sub> is the estimate of production for animal type *i* in year *t*, and  
Emissions Factor<sub>*i,1990*</sub> is the estimate of the emissions factor per unit of production for animal type *i* in 1990.<sup>6</sup>

This simple approach assumes that the emissions factor is not changing over time. The principal input required is the scenario of future production.

A more complex analysis should be conducted if the emissions factor per unit of production is expected to change in the future. A detailed assessment of the livestock production system is required, including an explicit assessment of how changes in production efficiency (e.g., increases in milk production per cow) will affect the size and performance of the overall national herd. Trends

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<sup>5</sup>The information required depends on the level of detail at which the emissions are estimated.

<sup>6</sup>The emissions factors discussed here are emissions factors per unit of product produced, for example kg of methane emitted per ton of milk produced. These emissions factors would be estimated by dividing the relevant emissions for 1990 by the level of production for 1990.

in the production of animal products, production levels per animal, and manure management practices should be considered.

Models capable of integrating the necessary information to conduct this assessment are not currently available. However, recent analyses have been conducted using the framework presented in Hallam (1983) in a spreadsheet structure (Woodbury and Gibbs, 1989).

### 12.4.2 Rice Cultivation

The IPCC/OECD emissions inventory method is recommended for developing the scenarios of emissions. This method uses the following equation for each rice growing condition  $i$ :

$$\text{Emissions}_i = \text{Area}_i \times \text{Emissions Factor}_i \times \text{Days}_i$$

where:

Area = area cultivated under rice growing condition  $i$  (hectares, ha);

Emissions Factor = emissions factor for rice growing condition  $i$  (kg/ha/day); and

Days = number of days under cultivation while flooded for rice growing condition  $i$ .<sup>7</sup>

While it is known that a variety of factors affect methane emissions, to date emissions factors have only been developed that vary by water management and temperature conditions.

For estimating base year emissions, the IPCC/OECD method recommends that the best available national data be used to estimate an average emissions rate for three years (e.g., 1989-1991). Data on rice growing area for all countries are available from the FAO Production Yearbook (FAO, various). For each country, IPCC/OECD (1994) presents default estimates of the season length (days) and the portions of the area that are: continuously flooded; intermittently flooded; and dry (rarely flooded). Emissions factors are also presented for the different water management and temperature conditions, although it is recommended that locally-derived emissions factors based on field measurements be used when they are available.

Future emissions can be estimated using forecasts of the growing activity. Future changes in area under cultivation and water management conditions must be considered. If locally-derived emissions factors are used that reflect differences in conditions such as fertilization practices, the baseline changes in these conditions should also be forecast. Data for these forecasts should be drawn from national agriculture planning studies.

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<sup>7</sup>Because more than one rice crop is grown per year in some areas, the number of days under cultivation would be the total number of days per year across all crop cycles.

### 12.4.3 Fertilizer Application

As discussed above, the information needed to accurately estimate baseline N<sub>2</sub>O emissions is not available. The IPCC/OECD emissions inventory guidelines allow a wide range of baseline emissions estimates to be developed using the following approach:

$$\text{N}_2\text{O Emissions}_{\text{Low to High}} = \text{N Applied} \times \text{Emissions Coefficient} \times 44/28$$

where:

N Applied = the tons of N applied to soils from chemical fertilizers, organic sources (animal manure and crop residues) and from biological sources (leguminous crops);

Emissions Coefficient ranges from a Low of 0.0005 to a High of 0.039, with a Median estimate of 0.0036; and

44/28 is the ratio of the molecular weight of N<sub>2</sub>O to the molecular weight of N in N<sub>2</sub>O.

The very large range of nearly two magnitudes between the low and high coefficients demonstrates the uncertainty in the current information available for making the emissions estimates. The IPCC/OECD guidelines recommend that the full range of emissions (Low to High) be estimated to convey the degree of uncertainty.

Sources of data for estimating the N applied are listed in IPCC/OECD (1994). Forecasts of N applied would be needed to develop a baseline of future emissions.

### 12.4.4 Soil Carbon in Cultivated Soils

The IPCC/OECD emissions inventory guidelines provide a method for estimating CO<sub>2</sub> emissions from soil organic carbon (SOC) in cultivated soils. To evaluate the mitigation potential of switching to conservation tillage practices, a baseline scenario of SOC characteristics and tillage practices is needed. In particular, the areas where conventional tillage techniques are likely to be viable should be identified.

The potential to accumulate SOC depends on highly site-specific climate, soil, and crop management factors. Simply stated, the change in the SOC content over time is a function of the carbon input rates and carbon turnover rates for each soil layer, as follows (Cole *et al.*, 1993):

$$d(\text{SOC})_i/dt = I_i - k_i \times (\text{SOC})_i$$

where:

SOC<sub>*i*</sub> is the SOC in carbon pool *i* (i.e., in each soil layer);



$I_i$  is the input to carbon pool  $i$  (from crop residues or other organic matter sources); and

$k_i \times \text{SOC}_i$  is the decomposition of carbon (i.e., turnover or loss) from carbon pool  $i$ .

The decomposition rate function,  $k_i$ , depends on climate, soil texture, tillage practices, crop residue characteristics, and similar factors. For sites with soil erosion by wind or water,  $k_i$  also inherently includes loss of SOC through transport of soil off-site. In this case,  $k_i$  does not necessarily represent the rate at which SOC is oxidized in  $\text{CO}_2$ . The uncertainty in the rate at which C is released or sequestered introduced by not knowing the fate of the SOC in eroded soil can be quantified by using an erosion model to estimate the amount of SOC removed by erosion, and then assuming that all or none of this SOC is released to the atmosphere.

Models such as EPIC and CENTURY may be used to assess how the various factors interact to influence SOC.<sup>8</sup> These models require detailed data on carbon inputs and factors that affect the turnover rate of SOC, including climate, soil texture, tillage practices, and crop residue characteristics. These data can be developed from national data bases when available, or from site-specific studies. Forecasts of future practices should consider ongoing trends in the use of various tillage techniques. Additionally, because weather conditions are an important factor affecting SOC, scenarios of future changes in climate (temperature and precipitation) may also be considered in the assessment (see, e.g., Woomer, 1993).

## 12.5 ANALYSIS OF MITIGATION OPTIONS

### 12.5.1 Enteric Fermentation

*Identify Target Sub-groups to be the Focus of the Emissions Reduction Effort and Refine the Emissions Estimates for the Sub-group*

The purpose of this step is to identify subgroups of the livestock population that are best to target for emissions reductions. Experts in animal nutrition and production within the country must be involved in this assessment. The following is recommended to identify sub-groups of the national cattle and buffalo populations that are most promising for emissions reductions:

- identify cattle and buffalo populations with relatively low levels of production efficiency;
- identify under-utilized or inefficient use of conventional and non-conventional feed resources that could be used for the population with low levels of production efficiency;
- identify the segment of producers with low production efficiency animals that can adopt improved production practices (e.g., those that are in organized cooperatives); and

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<sup>8</sup>The EPIC model is described in Sharpley and Williams (1990a and 1990b). The CENTURY model is described in Parton *et al.* (1992).

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- identify the segment of these producers that are a priority for economic development or for improvements in markets or marketing approaches, which would take advantage of the increased production efficiency of these animals.

For the sub-groups that are promising candidates for emissions reductions, detailed data should be collected for purposes of refining the methane emissions estimates. The Tier 2 (detailed) emissions estimating procedure described in the IPCC/OECD inventory method (or a comparable method) should be used. In addition to livestock population data, the following information is required for the detailed assessment:

- average weight of each animal type (kg);
- average weight gain per day (kg);
- feeding situation: confined animals; animals grazing good quality pasture; and animals grazing over very large areas;
- milk production per day (kg/day);<sup>9</sup>
- average amount of work performed per day (hours/day);
- percent of cows that give birth in a year;<sup>10</sup> and
- feed digestibility (%).<sup>11</sup>

These data should be obtained from national livestock experts. A detailed baseline of future emissions should be developed based on estimates of changes in these characteristics as well as future production levels.

### *Evaluate the Mitigation Options for the Sub-group*

The impact of each of the mitigation options applicable to each target sub-group should be assessed. The impact on emissions is estimated as follows:

- Identify how the mitigation option will affect the livestock characteristics used to estimate emissions. For example, the feed digestibility may be increased by 5 percent, or the milk production per cow may be increased by 15 percent.

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<sup>9</sup>Milk production is required for dairy cows and non-dairy cows providing milk to calves.

<sup>10</sup>This is only relevant for mature female cows.

<sup>11</sup>Feed digestibility is defined as the proportion of energy in the feed that is not excreted in the feces. Digestibility is commonly expressed as a percentage (%). Common ranges for feed digestibility for cattle are 50% to 60% for crop by-products and rangelands; 60% to 70% for good pastures, good preserved forages, and grain-supplemented forage-based diets; and 75% to 85% for grain-based diets fed in feedlots.

- Estimate new emissions factors per animal using the new livestock characteristics (the same method used to develop the baseline emissions estimates should be used). Estimate a new age structure of the livestock population if the mitigation option affects growth rates, reproduction, or mortality. Using these emissions factors per animal and the new age structure of the livestock population, estimate new emissions factors per unit of product produced.
- Estimate how the mitigation option will affect the overall production of animal products. In some cases overall production efficiency may increase as the result of improved production efficiency. Overall production will generally be constrained by feed availability and cost, however.
- Estimate the change in emissions using both the estimated change in the emissions per unit of production and the estimated change in production.

The costs of the options must be estimated in terms of: training costs; increased feed processing costs; infrastructure investment costs; and other costs. Estimates of costs will depend on local conditions and the details of the projects and programs being considered. These costs will be offset by benefits in terms of increased production efficiency and improved standards of living for rural populations. The costs and benefits should be estimated from the perspective of the individual producer as well as nationally. Only those options that are made to be profitable from the perspective of the individual producer will likely be adopted. ATI (1992) is an example of the type of assessment required in this step.

### 12.5.2 Manure Management System Facilities

*Identify Target Sub-groups to be the Focus of the Emissions Reduction Effort and Refine the Emissions Estimates for the Sub-group*

The purpose of this step is to identify subgroups of the livestock population that are best to target for emissions reductions. Experts in animal production and manure management within the country must be involved in this assessment. The following is recommended to identify sub-groups of livestock that are most promising for emissions reductions:

- identify livestock populations managed in large production facilities (typically large dairies and hog production facilities) that manage manure in liquid systems;
- identify livestock populations (typically small-scale dairy and draft cattle) whose manure is burned for fuel; and
- identify the segment of the large and small producers that would benefit from having an additional energy source, i.e., the methane recovered from the manure.

For the sub-groups that are promising candidates for emissions reductions, detailed data should be collected for purposes of refining the methane emissions estimates. The Tier 2 (detailed) emissions estimating procedure described in the IPCC/OECD inventory method (or a comparable method) should be used. The following information is required to conduct this assessment:

- annual average population (number of head) and climate region (cool, temperate, and warm);
- average daily manure volatile solids (VS) excretion (kg per day of dry matter);<sup>12</sup>
- methane producing potential ( $B_0$ ) of the manure (cubic meters ( $m^3$ ) of methane per kg of VS);
- manure management system facility usage (percentage of manure managed with each manure management system facility); and
- methane conversion factors (MCFs) for each manure management system used (the MCF defines the portion of the methane producing potential ( $B_0$ ) that is achieved).

A detailed baseline of future emissions should be developed based on estimates of future production levels and manure management practices. The approach recommended for developing a scenario of future emissions is the same as discussed above for enteric fermentation, with the addition of the consideration of changes in manure management practices.

#### *Evaluate the Mitigation Options for the Sub-group*

The impact of each of the mitigation options applicable to each target sub-group should be assessed. The impact on emissions can be estimated as the amount of methane that will be recovered that would otherwise have been emitted. USEPA (1993d) presents an example of how this analysis can be performed.

The costs of the options must be estimated in terms of: training costs; increased labor costs; infrastructure investment costs; and other costs. Estimates of costs will depend on local conditions and the details of the projects and programs being considered. These costs will be offset by benefits in terms of energy produced and the maintenance of the fertilizer value of the manure. Additional benefits may include reduced pressure on forest resources in rural areas for fuel and improved standards of living for rural populations. The costs and benefits should be estimated from the perspective of the individual producer as well as nationally. Only those options that are made to be profitable from the perspective of the individual producer will likely be adopted.

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<sup>12</sup>Volatile solids (VS) is a measure of the degradable organic material in livestock manure. The VS excretion rate is driven by feed intake and feed digestibility. Feed intake may be estimated using the Tier 2 emissions inventory method for enteric fermentation (IPCC/OECD, 1994).

### 12.5.3 Rice Cultivation

Methods for evaluating mitigation options for methane emissions from rice cultivation are in the early stages of development. As discussed above, research is ongoing to identify and evaluate various approaches for reducing emissions. Once reliable information is available on various options, the following general approach may be used to evaluate the options.

*Identify Target Sub-groups to be the Focus of the Emissions Reduction Effort and Refine the Emissions Estimates for the Sub-group*

To identify the most promising areas for emissions mitigation, a list of candidate mitigation options is needed, and the applicable conditions for each option must be identified and compared with a database of growing conditions in the country. For example, modifying water management to periodically drain the fields may only be practical in areas with secure irrigation supplies. A detailed database on national growing conditions, including irrigation status, would be needed to identify those areas that met the applicability criteria for the option. Such a database could be organized in a Geographic Information System (GIS), which would also facilitate the evaluation.

Once the target areas are identified, the emissions baseline for each should be re-examined. If possible, detailed site-specific measurement data from several years for these specific areas should be used to develop emissions factors. Additionally, estimates of days flooded should be developed for these specific target areas. Using these data, a detailed baseline of emissions for the target areas should be developed, as discussed above.

*Evaluate the Mitigation Options for the Sub-group*

The impacts of each mitigation option on the target areas should be identified. Data on the impacts of the options on the emissions factors would be used to estimate the changes in the emissions. Additionally, the costs of the options, including the impacts on rice production must be assessed. The data needed to evaluate impacts on emissions and costs are not yet available, however. Recent analyses, based on ongoing research results, that demonstrate this approach are presented in Kern *et al.* (in press), Bachelet and Neue (1993), and Bachelet, Kern, and Tolg (1993).

### 12.5.4 Fertilizer Application

Evaluation of mitigation options for managing N<sub>2</sub>O emissions should begin with the selection of land unit subdivisions to be analyzed. The analysis needs to encompass all of the major land resource (physiographic) regions in which agricultural crops are grown. These regions should be established on the basis of groups of similar physical, cultural, structural, and meteorological features.

The features involved in establishing physiographic regions include, but are not necessarily limited to the following:

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- **PHYSICAL:** Soils (soil survey information, soil nitrate levels, bulk density, texture classes, etc.), slope
- **CULTURAL:** Crops (type, yield), tillage, nitrogen application (all sources) and crop nitrogen uptake, conservation practices
- **STRUCTURAL:** Irrigation systems, land forming, e.g., terraces
- **METEOROLOGICAL:** Precipitation, temperature (Class A weather station preferable)

To complete the process of establishing physiographic regions for analysis, each of the above features will require specific data. Additionally, the analysts will need to determine the size of the areas according to extent of these features, and their overall importance to potential mitigation options. Expert judgement will be an essential element of this process.

Once the physiographic regions are established, it will be necessary to select the combinations of features that represent the majority of existing agricultural production systems within each region, and organize them into categories of typical production systems, such as non-irrigated conventional till maize (plant date & harvest date) grown on loamy sand soils (profile description needed) having an average land slope of 2%, average annual precipitation of 600 mm (seasonal and daily time steps will be needed), with a particular nitrogen management program (types, rates, timing, placement), etc.

Two (or more) runs of the NLEAP model could constitute the analytical process for evaluating mitigation options. The first model run would simulate the existing agricultural production systems, and the second would incorporate the options that contain changes in the way nitrogen is managed. The change in N-based gas emissions can be determined. This process is repeated for all physiographic regions and all typical agricultural production systems within the regions. Results from this process are summed to obtain totals for the country. The elementary cost of adjusting N management techniques can also be determined through use of NLEAP.

Although nitrogen management for N<sub>2</sub>O reduction is the focus of these evaluations, it is essential that the overall nutrient requirements of crops be evaluated before making decisions about how to best manage nitrogen. Without this approach, it is possible to minimize gas release from nitrogen that results in maximizing the movement of nitrate to groundwater or surface water, thus creating an undesirable tradeoff. Also, nitrogen management should be balanced within the total fertility program needed for individual crops. Phosphorus, for example, could become overloaded in the soil profile if care is not exercised. Implementation of comprehensive nutrient management programs will provide guidance needed to avoid problems. Nitrogen management options need to be integrated with the other mitigation options to identify optimal strategies. And finally, mitigation options need to be further integrated into an overall ecologically-based plan.

The costs and benefits should be estimated from the perspective of the individual producer as well as nationally. Only those options that are made to be profitable from the perspective of the individual producer will likely be adopted.

### 12.5.5 Soil Carbon in Cultivated Soils

Models such as EPIC and Century may be used to evaluate the impacts of conservation tillage on SOC. First, the most promising areas for switching to conservation tillage should be defined as the target sub-areas. Data for estimating the current and potential future SOC levels in the target sub-areas should be collected. This step may require field data collection.

Using the data collected, the SOC model(s) chosen should be calibrated to reproduce the current SOC characteristics of the areas based on past and current management practices. Once the model is calibrated to estimate SOC for past and current management practices, model parameters should be estimated using field data on the impacts of conservation tillage techniques on SOC. If possible, the results of local field studies of conservation tillage techniques should be used. If necessary, long-term field research should be initiated to develop the parameters needed to specify the models for the relevant local conditions. Examples of recent analyses of this type include Woerner (1993), Cole *et al.* (1993), Lee, Phillips and Liu (1993), and Kern and Johnson (1993).

Generally, the detailed analysis must be performed on a representative set of selected sites. The results for these sites are then extrapolated to the target sub-groups.

## 12.6 CONSTRUCTING BASELINE AND MITIGATION SCENARIOS

The purpose of constructing scenarios is to estimate future emissions with and without the implementation of the selected mitigation options. It is recommended that these scenarios be developed in detail for the target sub-groups for specific years, such as 2000, 2010, and 2025. The same models or techniques should be used to estimate both the baseline and the mitigation emissions scenarios for each of the sources.

The inputs needed to develop the scenarios are discussed above. The underlying forecast variables used throughout the analysis should be used as the basis for the future estimates. Ranges of assumptions should be developed for those parameters or estimates that are uncertain, and the implications of the uncertainty should be considered.

Two separate mitigation scenarios may be developed: (1) the technical feasibility scenario; and (2) the likely achievable scenario. The technical feasibility scenario examines the technical ability of the options to reduce emissions. It provides an upper bound on the emissions mitigation potential of the options examined. The likely achievable scenario takes into account the extent to which the mitigation options could realistically be adopted or implemented over time. The analyst should consider a range of penetration rates for the techniques based on penetration rates of similar technologies under comparable circumstances. A recent study by ATI (1992) for reducing methane emissions from ruminant livestock provides an example of how adoption rates can be included in an analysis. The analyses should also be explicit regarding the policies that will be undertaken to promote the adoption of the techniques and how the policies will affect the penetration rate.

## 12.7 MITIGATION POLICIES

### 12.7.1 Approaches for Implementing Emissions-Reduction Options

There are several key approaches for promoting the implementation of mitigation options in the agriculture sector. Generally, these approaches help to overcome the main barriers to the implementation of the mitigation options, which include: lack of information; lack of training; and inadequate economic incentives or economic resources (such as capital). Each approach is summarized briefly.

*Demonstration Projects.* Demonstration projects can be used to show that recommended technology practices are cost effective for producers. Research initiatives may be combined with demonstration projects to identify the preferred practice(s) for reducing emissions in a given location. Such projects would need to be targeted to the sub-groups discussed above, and may be needed in several regions with differing conditions. Demonstration projects are usually needed because agriculture producers are necessarily risk averse and as a consequence are slow to adopt changes in production practices.

*Pilot Projects.* Pilot projects are a step beyond demonstration projects. As such, pilot projects provide an opportunity to show how the proposed emissions reduction technique can operate on a larger scale. Necessary experience in project management, regional coordination, benefits assessments, and logistics can be obtained from pilot projects prior to implementing programs nationally.

*Education.* Education programs will be needed to disseminate information on the emissions reduction techniques. Education may be of two types:

- Formal education through the public school system and universities would target producers, agriculture professionals, and policy makers.
- Extension services include training and assistance from extension personnel. Services may be provided on-farm or off-farm at research or demonstration sites.

*Incentives.* Incentives may be needed to promote the use of the techniques. Examples include: direct financial assistance for expenses (e.g., capital costs or materials costs); subsidies for key inputs (e.g., for equipment); credit on favorable terms for investments in emissions reductions; and recognition for emissions reductions achieved.

*Direct Provision.* The inputs needed to reduce emissions may be provided directly to producers at reduced cost or for free. Examples include: providing information on the effectiveness of various techniques; providing training; providing infrastructure needed for undertaking mitigation options (e.g., irrigation for rice fields). In some cases, the program may involve commercializing products through the private sector, so that the government's involvement and subsidies are eliminated over time.



In addition to these approaches, various mitigation techniques could be required. For example, methane recovery from large manure treatment lagoons or conservation tillage on erodible land could be required. Requiring changes in production practices among small-scale rural producers is not likely to be preferred, however.

### **12.7.2 Considerations in Developing a National Strategy**

Key considerations in developing a national strategy for mitigating emissions from agriculture include the following:

*Scope.* The scope of the emissions reduction strategy should be well defined, including: the sub-groups to be targeted; the specific options to be promoted; the time frame over which the options will be encouraged; and the approaches to be used to promote the use of the emissions reduction options. Realistic penetration rates of the emissions reduction options should be used in the assessment of the total emissions reduction likely to be achieved. Experience with previous programs implemented in the relevant sectors in the country could be used to assess likely adoption rates.

*Coordination with Other Development Objectives.* The goal of reducing emissions from agriculture can often be combined with rural economic development objectives. The most promising options for reducing emissions will be those that also lead to improvements in the standard of living of rural populations. The national objectives for rural economic development and assistance must be considered during the development of a strategy for reducing these emissions.

*Food Security.* Any efforts to influence the agriculture sector must consider impacts on food security and trade balances. Options that reduce rice production are not likely to be economically feasible for most major rice growing nations. Alternatively, improvements in livestock production efficiency could enhance food security and reduce reliance on imports. Care must be taken to ensure that locally-available resources are used to improve food security; options that would result in over-reliance on imports may be inadvisable.

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## APPENDIX 12-1

### MITIGATION OPTIONS FOR ANIMAL HUSBANDRY: ENTERIC FERMENTATION

This appendix summarizes the mitigation options for animal husbandry enteric fermentation. This material is drawn from USEPA (1993b). These mitigation options reduce emissions by improving production efficiency. Most of the options are geared specifically toward developing country conditions.

**Improved Nutrition Through Mechanical and Chemical Feed Processing:** Improved nutrition reduces methane emissions per amount of product produced by enhancing animal performance, including weight gain, milk production, work production, and reproductive performance. Methane emissions per amount of digestible energy consumed by the animal may also be reduced. This option is applicable to accessible ruminant animals with limited feed resources. Assuming that feed digestibility is increased by 5 percent, methane emissions per unit product produced may decrease on the order of 10 to 25 percent, depending on animal management practices.

- Alkali/Ammonia Treatment of Low Digestibility Straws. This is a proven technique that improves feed digestibility and consequently animal performance (Owen and Jayasuriya, 1989). Many field trials have demonstrated its effectiveness. This process has been only partially implemented however, since it can be difficult to implement at the village level because it requires handling caustic materials. Additionally, adequate nitrogen in the animal's diet is required to take advantage of the increased digestibility.
- Chopping of Low Digestibility Straws. Chopping of straws can increase feed intake and consequently animal performance in some cases. This practice is limited in some areas due to lack of chopping equipment, which requires a moderate capital investment.

**Improved Nutrition Through Strategic Supplementation and Other Methods:** Improved rumen function will reduce methane emissions per amount of feed consumed. Also, by providing additional microbial and/or by-pass protein to the animal, emissions per amount of product produced will be reduced by enhancing animal performance, including weight gain, milk production, work production, and reproductive performance. Improved rumen function may reduce methane emissions by about 5 to 10 percent. In addition, emissions per unit product may be reduced by 25 to 75 percent due to substantial increases in animal productivity that are anticipated under specific conditions (Leng, 1991).

- Molasses/Urea Multinutrient Blocks. Balancing rumen function by supplying key supplements in a molasses-urea block (MUB) is a well described technique that may be targeted to animals on diets that lead to deficient rumen ammonia levels. Numerous field trials have been performed. Improved microbial growth improves the protein energy ratio for the animal and reduces methane production directly while improving

animal performance. Currently, implementation is limited by infrastructure and manufacturing capabilities.

- Bypass Protein. By-pass protein feeds (BPFs), or undegradable dietary proteins, are proteins that are not degraded in the rumen and are digested in the lower intestinal tract. BPFs improve animal performance by improving the protein-energy balance for the animal. BPFs are particularly effective for animals on low quality diets which do not generate adequate amounts of rumen microbial protein. Non-protein nitrogen (NPN) supplements such as MUBs, which stimulate microbial protein synthesis may be used in conjunction with BPFs. The BPF source must be available locally, and ideally should come from by-products of existing activities, such as distillery wastes or fish processing wastes. Currently, implementation is limited by a lack of evaluations of potential BPF sources as well as infrastructure and manufacturing capabilities.
- Targeted Mineral/Protein Supplements. Mineral/protein supplements may be targeted to specific circumstances to correct deficiencies in the diet. This technique has been applied to grazing animals in the U.S., and has successfully enhanced reproductive efficiency in beef cows. A lack of understanding of critical deficiencies combined with current market and pricing arrangements have limited implementation.
- Forage Quality and Grazing Management. For grazing animals, improvements in forage quality or modifications to grazing management practices can improve nutrition and reduce methane emissions per unit of product. Research is ongoing on a variety of methods for improving forage quality on pasture and rangelands, including: soil treatments; species management (e.g., legume-grass mixtures); water management; weed control; and erosion control. Rotational grazing and other stocking rate control methods are being investigated as means of improving forage quality and enhancing production efficiency.

**Production Enhancing Agents:** Certain agents can act directly to improve productivity. As a result, methane emissions per unit product will be reduced. Various agents are under development. Several that are currently available commercially include the following.

- bST. Bovine Somatotropin (bST) is a naturally occurring growth hormone produced by the cow's pituitary gland. Recombinant DNA techniques developed over the last 10 years now allow large quantities of bST to be synthesized. Development tests indicate that bST can improve milk productivity by 10 to 20 percent per lactation (Blayney and Fallert, 1990). It is also effective in promoting feed efficiency and repartitioning growth to lean tissues. The commercial use of bST has been approved in several countries and is under consideration in others.
- Anabolic Steroid Implants. Implants are a proven and commercialized technique for improving feed efficiency and repartitioning growth in beef production (USDA, 1987; Ensminger, 1983). However, these agents were banned in the European Union (formerly the EC, European Community).

**Improved Production Through Improved Genetic Characteristics:** Genetic characteristics are limiting factors mainly in intensive production systems. Continued improvements in genetic potential will increase productivity, and thereby reduce methane emissions per unit product.

- Crossbreeding in Developing Countries. The overall effectiveness of this technique is still a matter of dispute. Some claim that native breeds perform better under existing environments, and that genetic characteristics are not a limiting factor in production. As nutrition is improved genetic factors may increase in importance.
- Continued Genetic Improvement in Dairy Cattle. The genetic characteristics of dairy cattle are expected to continue to improve in the future. The major dairy countries have significant breeding programs in place. Detailed recording systems are used to perform quantitative assessments of the genetic potential of cows and bulls. Embryo cloning and transferring techniques, expected to be applied in the mid-term future, have the potential to accelerate improvements in the genetic potential of dairy herds.

**Improved Production Efficiency Through Improved Reproduction:** Large numbers of ruminants are maintained for the purpose of producing offspring. Methane emissions per unit product can be significantly reduced if reproductive efficiency is increased. The nutritional options described above can improve reproduction. Additionally, the following options address reproduction directly.

- Twinning. Techniques are being developed to produce healthy twins from cattle (e.g., inhibin vaccine). When combined with adequate nutrition for the mother and offspring, twinning can substantially reduce the total number of mother cows required to produce calves.
- Embryo Transfer. Embryos produced by superovulated, genetically superior cows can be transferred to foster cows of lesser genetic merit. This frees the superior cow from the long term pregnancy, redirecting energy towards increased ovulations. This technique has the potential to improve overall reproductive efficiency.
- Artificial Insemination and Estrus Synchronization. These are well known techniques that improve reproductive efficiency. Their implementation is limited to intensive systems where frequent contact with the cows is possible.
- Disease Control. Disease control will enhance productivity by reducing mortality rates and improving growth rates and reproductive efficiency.